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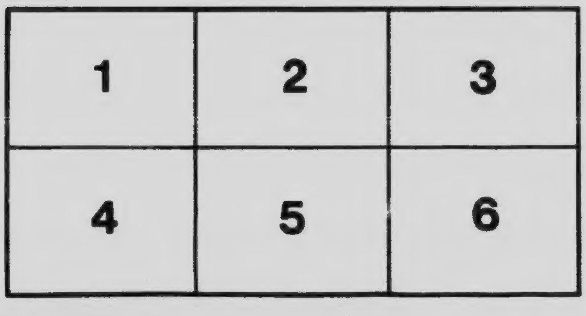

# UNIVERSITY OF TORONTO STUDIES

## PHYSIOLOGICAL SERIES

## No. 32: ON VENTILATION, BY J. J. R. MACLEOD.

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# On Ventilation*

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INVESTIGATION of the functions of animals is essentially a more difficult problem than that of the physicist or chemist because variable and unknown factors dependent on the life process are involved. The reactions of an animal to changes in the environment are therefore not always strictly predictable, even when we consider only measurable objective phenomena. Many of the problems of physiology consist in a study of the relationship between conditions of the environment and the behaviour of isolated living tissues. These studies are entirely objective in nature. When similar studies are made on the animal as a whole, subjective phenomena also have to be considered, and the results are much less predictable.

The well-being of a conscious animal in relationship to its environment constitutes the main problem of the study of ventilation. In the case of animals living an outdoor life, it is a problem of relatively little importance, but for those like man which spend much of their time in confined spaces, it is a problem of great importance, for in them it becomes necessary to determine the limits within which the outside influences may be altered without detriment to health or comfort. It is the problem which can be solved only by an understanding of the principles of ventilation, and I propose in this lecture to indicate briefly the state of our present-day knowledge with regard to principles, and to show how this knowledge can guide us in the selection of means to improve the conditions in our living rooms and indoor public places.

It is often imagined that ventilation is a matter merely of pure air and that it therefore becomes a problem requiring attention

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only in cases where the air has been polluted by the crowding together of many people. It is considered the problem of the ventilation engineer alone and not one that applies in living rooms in which there is no overcrowding. I shall endeavour to show, however, that this attitude is a wrong one, and that there is very good evidence for the belief that much discomfort and ill health could be avoided if people understood more clearly the physical conditions of the atmosphere which bear a relationship to the well-being of the body.

When our knowledge of the function of breathing became developed to the extent of showing that an animal requires the oxygen of the air for the living processes of its body, and as a result of these processes that it produces carbonic acid, which is then added to the air, it was natural to suppose that the unfavourable effect of overcrowded confined spaces was due either to the using up of the available oxygen or to a poisonous action of the carbonic acid. Indeed, it is still the notion of many people that one or other of these changes in the air is the cause of the discomfort of living in crowded places. It is true that a great deficiency of oxygen, such as occurs sometimes in mines because of oxidative processes in the soil, will very quickly cause serious symptoms, often indeed will produce a suddenly fatal result. And a lesser deficiency such as occurs in those unaccustomed to the rarefied air of high mountains, or in aeronautics, is undoubtedly responsible for most of the untoward symptoms classified under the term of mountain sickness. But that $O_2$ deficiency is not a usual factor in the evil effects of vitiated atmospheres is made plain when we state that even in the most overcrowded room a decrease of $O_2$ of one per cent.—*e.g.*, from 21 to 20—is practically never overstepped, a decrease which, however, is very much less than that which occurs at altitudes in which, after acclimatization, people live in perfect condition. Many of our best known health resorts and sanataria indeed are situated at altitudes in which the percentage of oxygen is greatly reduced, and there are large cities situated at altitudes of 8 or 10 thousand feet. In Pitosi, a city on the high plateaux of the Andes, the percentage of oxygen calculated at sea level is not more than 12 per cent., a reduction of 9 per cent. below the normal, and yet the people of this city are well and healthy and capable of as much effort as those living at lower altitudes. "Girls dance half the night and toreadors display their skill in the bull-ring."

Clearly, therefore, oxygen deficiency has nothing to do with the evil effects of ill-ventilated places.

With regard to a deleterious effect of the accumulated $CO_2$, similarly negative results have been obtained. This bold statement may possibly surprise some of you, for no doubt you have known that for a great many years the contrary was believed and that the percentage of $CO_2$ in the air was taken as the criterion of the adequacy of ventilation. So firmly rooted indeed has this conception become that it has required considerable investigation to overthrow it. Although it has been known to physiologists and hygienists for many years that accumulation of $CO_2$ has nothing to do with the evil effects of polluted air, it is still believed by the laity to be the really important factor, so slowly does the work of the scientist find its application in the life of the community.

It is not altogether easy to understand why excess of $CO_2$ was thought to be the important factor responsible for the evil effects of vitiated atmospheres. No doubt the chief reason was that the percentage of this gas is often raised in such atmospheres, but this is nothing more than coincidence, for, on the one hand, most unsuitable conditions may exist when the percentage of $CO_2$ is normal, and on the other, air loaded with almost a hundred times the percentage found even in the most polluted atmosphere can be breathed for indefinite periods of time without any unfavourable symptoms.

As a matter of fact, even in the open, we are constantly taking into the air sacs of the lungs large percentages of $CO_2$, for obviously with each inspiration the first air to be drawn in is that which remains over in the air passage from the preceding expiration. This air contains somewhere about 5 per cent. of $CO_2$, and in quiet breathing it amounts in volume to about one-third of all the air that is drawn in from the outside. This alone indicates that $CO_2$ *per se* cannot be poisonous, and when we consider further the now well-known fact that a certain amount of this gas in the air sacs is absolutely essential to the well-being of the animal, the whole hypothesis of its toxic action becomes, to say the least of it, absurd. Indeed, so important is the presence of this constant amount of $CO_2$ in the alveolar air that whenever there comes to be a marked increase in the amount of $CO_2$ in the atmosphere, the breathing becomes greater, so as to ventilate the air sacs more thoroughly, and thus keep the relative amount of $CO_2$ in them at the normal level. The extent of this increase in respiration is usually so small as to be unnoticed by the individual, and certainly increased breathing is not one of the symptoms of which persons complain who are living in polluted atmospheres. Furthermore, not only man, but other animals as well, frequently breathe by choice under conditions which cause great increase in the $CO_2$ content of the inspired air. "Not only the new-born babe sleeping against its mother's breast, but pigs in a stye, young rabbits, rats and mice clustered together in their nests, young chicks under the brooding hen, all alike may breathe a higher percentage than that legally allowed in spinning mills or weaving sheds." . . . "In breweries the men who tend the fermentation vats work for long hours in concentrations of $CO_2$ of 0.5—1 per cent. Such men are no less healthy and long lived than those engaged in other processes of the brewery trade." (Leonard Hill.)

In face of such evidence, even the most ardent supporters of the theory that the vitiated air owes its evil influence to $CO_2$, were compelled to abandon their position, but they did not do so without a final attempt to retain for determinations of $CO_2$ a certain significance in the appraisement of the healthfulness of air. Their new interpretation was to the effect that the $CO_2$ percentage is proportional to the amount of deleterious organic matter, and for many years this view prevailed. It is still believed by some that an increase from the normal to 10 parts of $CO_2$ per 10,000 parts of air indicates a degree of organic pollution which is dangerous to health. More recent work definitely shows, however, that this view also must be abandoned, and there remains for $CO_2$ analysis only the secondary value that it indicates, in a readily measurable way, to what extent the inside air is being mixed by ventilation with pure air from the outside. However free this dilution may be, the atmosphere may still be deleterious to health and comfort unless certain other properties of it are incidentally altered.

This interpretation of the value of $CO_2$ analysis naturally leads to a consideration of the next possibility, namely, that the air in confined spaces is contaminated by the accumulation of organic poisons derived from the exhaled air of the persons living in it. It is many years ago now since experiments apparently proving this hypothesis were published. These consisted in placing small animals, such as mice, in a series of glass vessels connected together in series by tubing. Air was sucked through the series so that the animal in the second vessel received air that had been polluted by the animal in the first one, and the third by the first and second, and so on. It was found that the animals in the last one or two vessels of the series died after some time, whilst the others remained perfectly healthy. The original experiments were very improperly performed, however, and their repetition with proper care to keep down the $CO_2$ below a concentration which *is* fatal, such as 10 or 15 per cent., has not afforded any evidence that organic poisons were contained in the air.

Some of those who sought for evidence in support of this hypothesis, did experiments that border on the ridiculous, but yet it is important that they be referred to here, since they are sometimes quoted as being trustworthy. These experiments consisted in collecting the condensed vapours of expired air and then inoculating small animals hypodermically with some of the condensed liquid. About 1 c.c. was found to kill a mouse, and, no wonder, since this would mean an injection of something like 5 kg. into a man of average weight. Everyone knows what the injection of so much water would do. Even distilled water is highly toxic in much less amounts when it is injected subcutaneously, and when we add the fact that this condensed vapour was contaminated not only with various salts, but also with bacteria, the result on the mice becomes utterly meaningless.

During more recent years the attempt has been made to resuscitate the old hypothesis by supposing that the toxic substance is of the nature of a volatile protein. When the proteins of one animal are introduced, even in very minute quantities, into another animal in any other way than through the alimentary tract—for example, by being absorbed through the lungs—they set up in the body a peculiar condition, in which the animal becomes so very sensitive to that particular protein that when another minute quantity of it enters the body a serious poisonous reaction which is often fatal results. The phenomenon is called anaphylaxis. It was supposed that in a milder form a reaction of this type was responsible for the toxic influence of vitiated air. As proof for this hypothesis experiments were performed in which a man breathed through a filter of glass wool (to catch any saliva) into a cooled vessel, and the condensed vapour was then inoculated in appropriate dosage into guinea pigs, so as to sensitize them, and a month or so later the animals were inoculated with a minute trace of human blood serum. The injected animal showed decided symptoms of anaphylactic shock, whereas other animals not previously sensitized were unaffected by the injection of the same amount of serum. Such results taken by themselves did seem to afford substantial support for the new hypothesis, but it is almost certain that they depended on contamination of the condensed vapour by traces of saliva which it is impossible to keep out by any kind of filter. This saliva contains traces of soluble protein (mucin) which had been responsible for the anaphylactic reaction. The symptoms are, however, entirely dissimilar from those of a vitiated atmosphere. Hay fever and the reaction which some persons show when near to horses may be due to anaphylaxis, but the symptoms are not at all like those of persons breathing polluted air.

Once and for all, the toxic theory, as we may call it, both in its new and its old form, is disproven by a very simple series of experiments performed a few years ago by Leonard Hill, Flack and others. These observers kept rats and guinea pigs in deep boxes so that they were huddled together in a very poorly ventilated place, the atmosphere of which indeed often contained 1 per cent. of $CO_2$—ten times more than the legal limit. The animals lived and thrived for months, although they must have been breathing air which was highly contaminated by the supposed volatile proteins. Not only did the animals show no symptoms while in the box, but they failed to exhibit any anaphylactic reaction when, after some time, they were inoculated subcutaneously with the serum of animals of the other species with whom they had been in cohabitation. This was really a most excellent test of the anaphylactic theory because there are probably no two animals in which anaphylaxis is more pronounced than in the rat and guinea pig. The only things that were found to be of importance in maintaining the animals in a thriving condition were cleanliness and plenty of food.

By an eliminative process we are gradually approaching the correct solution of our problem, but before we proceed to consider this, it may be well to remark that the odour of polluted air has nothing whatever to do with its unhealthy influence, except in so far as it excites disgust and puts one off his appetite. Indeed, one very soon becomes so accustomed to these odours that they fail entirely to be sensed after a short period in contact with them. Their influence is entirely psychological. In many trades and occupations people are constantly exposed to odours that are almost unbearable to one who is unused to them, and these people are perfectly healthy, and, indeed, do not complain at all of the smells.

We have so far considered in what is approximately their chronological order the various hypotheses that have been brought forward to account for the harmful influence of vitiated atmospheres. We have done this mainly in order to correct any false conclusions that may still exist in connection with the subject.

And if further evidence be demanded to justify this position there is one crucial experiment which once and for all shows that changes in the chemical composition of the atmosphere has no relationship whatsoever to the unhealthful influence of vitiated air. This experiment is all the more convincing because it was performed on healthy young men. In its simplest form it consists in crowding as many persons as possible into an air tight cabinet, provided with an electric fan, and with the necessary apparatus for measurements of the physical and chemical condition of the air. In describing the results of this experiment, I cannot do better than quote from Leonard Hill, who, though not the first to perform the experiment, has so greatly extended our knowledge of the science of ventilation during recent years.

"After 44 minutes the dry-bulb thermometer stood at 87°F., the wet-bulb at 83°F. The carbon dioxide had risen to 5.26 per cent. The oxygen had fallen to 15.1 per cent. The discomfort felt was great; all were wet with sweat and the skin of all was flushed. The talking and laughing of the occupants had gradually become less and then ceased. On putting on the electric fans and whirling the air in the chamber the relief was immediate and very great, and this in spite of the temperature of the chamber continuing to rise. On putting off the fans the discomfort returned. The occupants cried out for the fans. No headache or after effects have followed this type of experiment which has been repeated five times." Long before the discomfort had become extreme the oxygen percentage became so low that matches would not light. The disinclination to smoke cigarettes was not noticed until some time after it was impossible to light them.

In other experiments of similar type the person in the cabinet was allowed to breathe outside air through a tube, but with no amelioration of the uncomfortable feeling, or a person outside the chamber breathed for hours the air inside it through a tube without suffering and discomfort. Clearly, therefore, neither the chemical nature of the air, nor the presence of toxic substances in it, has any relationship to its evil influence. But the experiment is not merely destructive of previously held hypotheses; it also points the way to the true solution of the problem, for it indicates that stagnation of air loaded with moisture has some very close relationship to the discomfort. It shows that a change in the physical, rather than the chemical properties of the air is the real cause of its deleterious action.

These changes can affect but one function of the body, namely, that of heat dissipation, and by so doing cause disturbances in the mechanism of heat control. This does not necessarily imply that this disturbance is so great as actually to cause an increase in the body temperature, although this is very commonly observed in persons who have been for some time in crowded places. It indicates interference with a mechanism which is responsible not alone for proper heat regulation, but also for the maintenance of a proper relationship of blood supply to different parts of the body, and for toxic stimulation of the nervous system.

At this stage it may be well to digress for a moment to explain how the body temperature is maintained. To a certain extent the mechanism is exactly that of a radiator, the temperature of which depends, first on the rate at which the furnace is burning and second, on the cooling influence of the air in contact with the radiator. The physical properties of the air upon which the cooling depends are those which influence radiation, conduction and convection. Now, turning to the body, these processes come into play mainly at the surface of the skin, where, however, excessive loss is guarded against partly by the low conductivity for heat of the skin and of the subcutaneous tissue (fat), and partly by the fact that the blood supply to the skin is scanty compared with that of the deeper tissues. This causes the blood flowing in the skin to have a decidedly lower temperature than that in the tissues a few millimeters deeper. This relationship of superficial and deep temperatures is maintained by the action of vasomotor nerves to the blood vessels, and whenever the body is exposed to warmer air, the vessels of the skin become dilated so as to draft more blood from the deeper to the superficial vessels causing flushing of the skin. Flushing of the skin is therefore a normal reaction, but at the same time it is a warning that the heat-regulating mechanism is being put on a strain. But it is inadequate to account for all the heat loss, for man can withstand temperatures that are not greatly below those of his body, indeed, he can tolerate for some minutes temperatures that are higher. It is recorded, for example, that two observers exposed themselves for a short time in an oven in which a steak was cooking, and it is well known that certain miners work for considerable periods at very high temperatures.

Evidently some other mechanism independent of the cooling effect of air itself, and not acting in the case of a radiator, comes into play. This is evaporation, and it occurs at two places in the body; at the surface of the skin, where sweat is evaporated, and in the lungs where the expired air is saturated with water vapour. The physical factors which control the degree of heat loss by evaporation at these two places are not precisely the same. In the case of the lungs the inspired air becomes saturated with water at body temperature, and the amount of evaporation necessary to do so depends upon the amount of water already contained in the inspired air, that is, on the absolute humidity; the lower this is, the more water will it require to effect saturation.

In the case of the evaporation of sweat, the amount of moisture vapourized from the body depends on the relative temperature and the humidity of the atmosphere.

It may be well to digress for a moment to explain what is meant by these terms relating to humidity. By absolute humidity is meant the weight of water contained in a unit volume of air. This increases greatly with the temperature of the air; thus at 70°F. one cubic foot of air contains 7.91 grs. of water. Relative humidity, on the other hand, means the degree to which the air is saturated with moisture at each temperature; thus, a relative humidity of 75 at a temperature of 70°F. means that it contains 75 per cent. of the total of 7.91 grs., which, it would contain if saturated at this temperature.

Now, inasmuch as the air after expiration is at about the same temperature as the body, and is practically saturated with moisture, it follows that the main factor influencing loss of heat by this means will be the amount of moisture actually present in the inspired air. If this be nearly at body temperature, 97°F., and dry, each 100 c.c. will take up .00413 gm. water in the lungs; if it be at average room temperature (say 68°F.) and dry, it will take up just exactly the same amount to become saturated with vapour. Some heat, it is true, will also be required in this latter case to raise the temperature of the air itself, but this is small when compared with that required to hold the water as vapour, since air warms up easily, or, to use the scientific term, has a low specific heat.

The amount of heat dissipated from the body of man by this means in an ordinary living room is about 10 per cent. of the total loss, but it becomes relatively much greater when the air is dry, and especially when the breathing is increased. On the other hand, when the humidity of the outside air is great and the temperature high, little heat loss occurs through this pathway.

Under ordinary conditions of living somewhat less heat is lost by evaporation of the sweat, and the factors which mainly determine it are the temperature and the relative humidity of the atmosphere, provided the temperature be above a certain level.

It is in connection with this phase of the subject, more than any other, that many people find it difficult to understand the true significance of relative humidity to the well-being of the body. The difficulty depends on the fact that the relative humidity has an opposite influence at low and high temperatures. In the former case it increases the conductivity of the atmosphere for heat and has a cooling influence, and in the latter it interferes with the evaporation of sweat, and has a heating influence. Below about 65°F. the cooling effect of moist air is prominent because there is little sweating, therefore a cold, wet atmosphere is chilling—it conducts heat away. At about 70°F., the cooling effect of air disappears and sweat occurs. The evaporation of the sweat now causes cooling, the degree of which varies inversely with the relative humidity. Between these two temperatures, *i.e.*, 65 and 70, there is a range in which humidity has little influence—a neutral region. The influence of high relative humidity on bodily comfort at temperatures above the neutral temperature becomes very marked indeed at 85°F., and a relative humidity of 90%, for example, very serious symptoms appear in a few minutes, when there is no movement of the air.

Relative humidity and temperature alone are not, however, the only physical conditions to be considered. Another is the movement of the air, for even under the unfavourable conditions just cited immediate relief is afforded if an electric fan be started, as it will be recalled was the result in Hill's experiment. The temperature in the cabinet was 87°F. dry bulb, and the relative humidity very high indeed when the symptoms became serious; by turning on the fan these conditions of the atmosphere were not altered, but the students immediately felt comfortable. The movement of the air enables it, though nearly loaded to its full capacity with moisture, to carry away considerable quantities in small loads.

The wearing of clothes greatly affects the rate with which these changes occur. The clothes act as barriers preventing the movement and exchange of air around the body. The garment next the skin entraps a layer of air which is more or less at the same temperature as the skin, and which soon becomes saturated with moisture at that temperature. Between the inner garments and those over them other layers of air are entrapped, each one being at a somewhat lower temperature and containing less moisture than the one inside. These layers of air, therefore, form stepping stones as it were between the extreme conditions at the surface of the skin, and the environment of the clothed body. Obviously if the layers of air next the skin are to be renewed at such a rate that they remain cooler than the skin and unsaturated with moisture the clothing must be adjusted to suit the outside conditions.

There is every reason for believing that it is because of interference with these processes that improperly ventilated and overcrowded places are uncomfortable. The moisture exhaled and evaporated from the bodies soon raises the relative humidity so that heat loss is retarded from the skin, and the heat that is actually given off raises the temperature so that loss from the body by radiation and convection becomes suppressed. As the temperature steadily rises, the air takes up more and more moisture, with the result that less and less heat comes to be lost from the lungs in saturating the expired air with vapour. The physical conditions of the environment become unsuitable for the physiological mechanism of heat loss, although meanwhile heat production goes steadily on. The body furnaces are not damped down in proportion as the loss of heat diminishes, and the consequence is a rise in the temperature of the blood—a mild fever. Now it is well known that the cellular activities which, taken together, make up the life process of the body are extraordinarily sensitive to change of temperature; their chemical processes become changed, they demand more oxygen, they fail to get rid of effete products properly, substances which have no action on them under the ordinary conditions of temperature become toxic, and so forth. A highly abnormal internal environment therefore becomes created around the living tissues of the body.

But short of a measurable rise in the temperature, improperly ventilated places cause reactions in the human body that are responsible not only for the discomfort which is experienced, but also for a lowering of resistance to infections. These reactions are due in the first instance to alteration in the temperature differences between the skin and the underlying tissues. Normally, as has been remarked before, this difference maintains at the skin a constant stimulation of the thermic nerves, and this stimulation is important in maintaining the tone of the nerve centres. The nerve cells that control the functions of the body do not originate impulses; they only act when other afferent impulses arrive at them. There are many varieties of stimuli which may excite these afferent impulses, but none more important than those which excite the heat nerves of the skin. This stimulation depends on changes in the rate at which heat is passing through the sense organs in which these nerves terminate. It is necessary to emphasize that it is the rate of change that acts as the stimulus and this depends on changes set up between the deep and superficial temperatures. When the skin vessels become dilated so large a volume of blood reaches the surface that this difference becomes slight and the thermic receptors are not stimulated. There are many practical applications of these principles, thus it is because of stimulation of the thermic skin nerves that cold baths have a bracing effect, that the open air treatment, as in tuberculosis, tones up the body and enables it the better to hold its own against the tubercle bacillus and that sleeping out of doors is the best tonic for maintaining good health. In open air treatment it is true that the body is closely wrapped up—that is essential—but this does not eliminate the cooling influence, for not only does the cool air play on the exposed face and hands, in the skin of both of which the thermic nerves are very sensitive, but it acts also on these nerves in the skin, under the clothes, for the clothes merely serve to regulate the rate of cooling. This still goes on very much more than it would with much less clothing in an atmosphere that is stagnant, hot and humid. Open windows in bedrooms are never so healthy as open air porches, because there is no draft. It is the draft that is important. Naturally it must be regulated so that it is not restricted to one part of the body only—that obviously would introduce conditions to which the body is unaccustomed—it must blow equally all over. There is probably no greater fallacy in popular hygiene than that drafts are dangerous. Like all good and desirable things they become so only when they are improperly used. When a person, overheated by being in a hot atmosphere, is suddenly subjected to a restricted draft of course there [illegible] danger that the sudden change of conditions, affecting one part of the body only, will cause vascular disturbances that may be undesirable, but if the conditions be properly controlled, drafts are the healthiest things and the best tonics.

This brings us to a problem in ventilation that is attracting very considerable attention at the present time, namely, the relationship between ventilation and infections. It is a common experience not only that ordinary colds, but more serious infections as well, can be directly traced to some unsuitable condition of ventilation; such as sudden exposure to a draft while overheated, or going out into a cold, damp atmosphere from an overheated room. What is the reason for the infection under these conditions? At the outset we must recognize that all these conditions, colds, catarrhs, bronchitis, just like the more acute infectious diseases like diphtheria, pneumonia, cerebro-spinal fever, etc., are due to micro organisms, and the question therefore is why should unfavourable ventilating conditions so frequently be the immediate cause of the attack.

There are two methods by which the infection might occur. First, by a great increase in the number of organisms in the air, and, secondly, by a lowering of the resistance of the body towards the organisms, which would not then require to become increased in numbers. The former method is usually known as mass infection, and there can be no doubt that it is very common, perhaps, indeed, it is the commenest cause for infection. The organisms, of course, come from infected individuals, who add them to the atmosphere in the exhaled air, particularly when this is forcibly discharged as in coughing, or sneezing, or even in speaking.

I need recite to you only a few observations to convince you of the importance of this factor. If the mouth be rinsed with a culture of some readily recognizable organism not commonly present in detectable amounts in the atmosphere, and the person, standing in front of a row of plates each containing some culture medium upon which the organism will grow, then speaks at ordinary pitch, the plates after proper incubation develop colonies of the organism, those nearest the speaker having most, but even those at a distance of several feet also showing them.

A serious problem in zoological gardens has been to keep animals that are highly susceptible to tuberculosis free from this disease. The higher apes, for example, inevitably succumb to this disease, being infected by the bacilli exhaled by persons standing in front of their cages, many of whom harbour the tubercle bacilli, though they may not show any of the symptoms of tuberculosis. Now it has been found that if glass screens are erected in front of the cages the animals remain almost free from the disease. The lesson which these and many other similar observations teach us that we should avoid as much as possible getting in the direct path of the exhaled air even of apparently normal individuals, and when an infectious disease is prevalent, it should not be considered rude in conversation to stand aside a little and even to hold the hand, or better still, a newspaper, before the mouth. This may seem impracticable advice. But why so? In the light of such convincing experiments as those which have been cited above, and they are only two in a multitude—why should people not be more careful about being infected, especially during dangerous epidemics such as that of influenza. The thing to bear in mind is that a person may be harbouring the deadly bacteria and yet be in perfect health. The bacteria that are inocuous to him may find in another person more favourable conditions for growth, and so produce the disease.

But mass infection does not suffice to explain the cause for the onset of attacks of many conditions that are nevertheless fundamentally due to bacteria, such as ordinary colds. These can frequently be traced to some chill, or wet feet, or exposure to sudden change in temperature. In such cases it is believed that the bacteria are present on the mucous membranes of the upper respiratory passages, but that they remain inactive because of the normal protective influences which exist on these surfaces. So long as the blood supply is normal, these protective influences are adequate to protect the body from invasion, but if this should become curtailed, then the bacteria become active and set up pathological processes. Evidence favouring this view has been obtained by several recent investigators by finding that the blood supply of the upper respiratory passages becomes decidedly curtailed when the surface of the body is cooled. For example, Leonard Hill and Muecke some years ago examined with a speculum the mucous membranes of the nose under various conditions, particularly out of doors, and in rooms which were ventilated and heated to an average degree. Out of doors the mucosa was pale and taut, and when touched by a probe did not show any pitting. This is the normal condition. Indoors it was common to find the membrane decidedly swollen, flushed with blood and covered with thick secretion, and when a probe was pressed on it a depression resulted lasting for some time. In one case that was frequently examined during these observations there was a deflected septum which only partly blocked the nasal passage on one side when the person was outside, but which did so completely under unfavourable conditions of ventilation. It is this swelling of the nasal mucosa and probably of that of the cavities which extend upward from it on to the forehead that causes the sense of stuffiness and probably also the headaches which are common in crowded, over-heated places.

The conditions found to bring about these changes with greatest certainty were when the feet were cold and the air round the head was warm, conditions which are just exactly the opposite of those obtaining out of doors. Here the head is usually more quickly cooled than the feet, because convection currents of cool air play around it freely, whereas next the ground the air is more stagnant. Besides, if the sun is shining, the earth becomes heated by absorbing the heat. The temperature as registered by a thermometer, either wet or dry bulb, may be the same at the feet as at the head. It is not this that counts, however; it is the rate of cooling which is dependent mainly, on the movement of the air. Now, in a poorly ventilated room, such, for example, as one heated by a stove, or even by radiators, and in which there is no movement of air, the feet become colder than the head, and it is under these conditions that the nasal membranes become swollen. Leonard Hill, to illustrate the importance of these principles, cites an interesting observation which he made in the House of Commons. In the main chamber "the ventilating current is driven up through the floor in such a way as to cool the members' feet, while their heads are exposed to more stagnant air. Cold feet and stuffy heads result—just the wrong conditions for legislators." The thermometer shows a uniform temperature, but the Kata thermometer, which we will describe shortly, shows the cooling rate to be 40% greater at the feet than at the head level. Hill states that he always experienced obstruction of the nose, because of his deflected septum, when he sat on the benches, and that this disappeared when the air coming through the floor was cut off and the air was introduced at the head level. The cause for these changes is not cold feet alone. It is the combination of cold feet and hot head. Out of doors, it is well known, that any one may stand with cold feet for hours without any risk of catching cold, but then the head is really cooling as fast as the feet, because of convection currents.

The ideal system of warming a room is to supply radiant heat near the floor level; open fires, properly flued modern gas fires, and electric heaters at floor level are the best methods to attain this. Steam heated radiators, especially if they are provided with vapourizers, are not desirable methods for heating unless the air of the room is frequently changed at high levels.

Suppose now the person subjected to conditions which cause the mucous membrane to become swollen and congested should go outside, then the membrane at once becomes pale because the blood vessels constrict, but for some time it remains swollen and boggy and continues to show pitting with a probe. It is while in this state that it offers favourable conditions for the growth of bacteria. The membrane is swollen and covered with secretion, and the blood flow is cut down. The natural defensive agencies that are normally carried by the blood do not succeed in combating the multiplication of the bacteria in the swollen membrane. After some time out of doors the blood supply returns because it is required to warm up the cool air, but this reaction does not occur before the mucosa has regained its normal condition.*

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*The congestion of the mucous membrane brought about by warm, moist air, does not probably depend on dilatation of the small arteries—entailing increased flow of blood, but rather on dilatation of the capillaries, and therefore a stagnation of blood.

The protective influence of a rapid blood flow through the nasal membrane is possibly the explanation of the relative immunity from infectious colds of those who work in air containing irritating gases, such as workers in various kinds of chemical factories. Even the irritation set up by coal dust may, by similar methods, afford some protection against infection by the tubercle bacillus—for phthisis is relatively infrequent amongst coal miners. The supposedly antiseptic action of ozone is probably due to a similar irritating effect. Any benefit that may be derived from its presence in the atmosphere cannot otherwise be explained. It is possible that a useful prophylactic practice to avoid infection, such as that of influenza, would be to stimulate the nasal mucosa at intervals by snuff, but this may be an unwise suggestion.

After becoming acclimatized to outdoor conditions the nasal mucous membrane is in a much more favourable condition to withstand infection than indoors, because of the very rapid blood flow that is necessary in order to supply heat with which to warm up the inspired air. This more rapid blood flow, and the freer flow of lymph which accompanies it, is reinforced by increased secretion, which assists to wash away invading bacteria. Mass infection being equal inside and outside, the animal body can withstand it much less satisfactorily in the former case.

These observations on the reactions of the respiratory membranes to atmospheric conditions have been confirmed by other investigators. Thus Cock (H. Girard Cock, Tr. Am. Laryngol. Rhinol. & Otol. Soc. June, 1915) caused persons to breathe forcibly through the nostrils on to a mirror surface, and then marked on it with a wax pencil the outlines of the moisture deposited. Although the extent of the outlines varied somewhat with the depth of breathing, they afford a general estimate of the width of the air passage. It was found that there is marked reduction in the nasal air passage in a warm room. Winslow (Winslow, C.E.A., New York Commission on Ventilation) also sums up the observations (150 in number) made on this aspect of the problem, in the following words: "Ordinarily it was found that heat causes a swelling of the inferior turbinate of the nose, tending to diminish the size of the breathing space, increased secretion and reddening of the membranes. The action of cold is, as a rule, just the opposite."

Many other observations bearing on the relationship between chilling and immunity to infection have been recorded, but it would take us beyond our subject to discuss them here. Because of their accuracy and the excellent control of possible fallacies it is important, however, to say something about the recent investigations of Mudd and Grant (Mudd, S. and Grant, S. B. The Journ. of Medical Research, XL., p. 53, 1919). These observers measured the temperature of the mucous membranes of the palate, tonsils and pharynx by means of thermo-couples before and during application to the skin of cold towels, or while cold air from a fan was allowed to play on it. A rise in temperature would indicate that the part had become more vascular, and a fall, the contrary. That this interpretation was the correct one was confirmed by direct inspection of the degree of flushing (redness). It was found that chilling the body surface immediately caused a fall in the temperature of the mucous membranes which could not be accounted for by any accompanying change in blood pressure, or, entirely at least, by changes in respiration or by lowering of the temperature of the blood. The conclusions are "that chilling of the body surface causes reflex vaso-constriction and ischaemia in the mucous membranes of the palate, faucial tonsils, oropharynx and nasopharynx."

And now the final question presents itself, what are the ideal conditions of ventilation? It is a most difficult question to answer, and one over which at present several large commissions are at work. Indeed, most elaborate experiments have been planned and undertaken to throw light on the question. The observations of the New York Commission on Ventilation, by Mr. Watt, in the Graham School in Chicago, are among the most important in this country, and, of course, they interest us much more directly than those conducted on the other side, where the climatic conditions are fundamentally different.

The observations have been made very largely on properly selected groups of school children, taught in class-rooms with different ventilating conditions. Attention is directed to the general efficiency of the pupils and the condition of their health. The temperature, and the humidity of the air are the physical conditions of the atmosphere which have been more particularly studied, but a great deal more work must be done before any definite conclusions can be offered. It appears, however, that for schoolroom air a temperature of 65-68°F., with a relative humidity of 45-60% is the optimum. To maintain these conditions throughout the period a class occupies the room, usually requires, in this country at least, the addition of a considerable quantity of moisture to the ventilating air. The air of most of our school rooms in winter errs on the side of being too dry, for under these conditions the mucous membranes suffer injuriously. An excellent summary of the variou authoritative conclusions with regard to the optimum condition of ventilation for class-rooms is given by Burnham in the *Pedagogical Seminary* (Burnham, W. H., *The Pedagogical Seminary* 1919, XXVI., p. 311).

Although the present review does not venture to discuss th methods that are employed for the measurement of the variou physical properties which have to be considered in gauging its influence on health, nor the engineering problem of how ideal conditions may be maintained, it may not be out of place to mention, i connection with the former of these, that the physical property t which most attention should be devoted is the cooling power. Th cannot be done by reading an ordinary thermometer, for this instrument only registers the temperature of the piece of wood an of the wall against which it is hung. It registers the same whethe the air is dry or moist, or whether it is stagnant or moving. Somewhat more information regarding cooling power is afforded b readings of a wet-bulb thermometer, an instrument in which th bulb is kept constantly moist, so that evaporation occurs from it This evaporation tends to cool the thermometer, in proportion t its rate, and since this is dependent mainly on the degree to whic the air can take up more moisture, we can tell by the use of formula or tables the relative degree of humidity of the air Still this does not tell us the real degree of cooling which th atmosphere can bring about. It does not adequately register th cooling which is dependent upon movement in the air, the so-calle convection currents. To afford this information Leonard Hill ha invented what he calls the Kata thermometer, by which the ra of cooling is directly measured. The instrument consists of a alcohol thermometer with a relatively large bulb, and with the scal registering between 105°F. and 90°F. It is placed in warm water a about the former temperature, and is then removed, and the tim required for the temperature to fall from 100°F. to 95°F. is measured by means of a stop watch. This time divided by a factor determined for each instrument, and written on the stem, gives the actua amount of heat in millicalories per square centimetre per secon which would be given off from, say, the surface of the huma body, under similar environmental conditions. Hill and his associates have shown that much important information concerning th cooling power of the atmosphere can be gained in this way, whic cannot be gained by any other.

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